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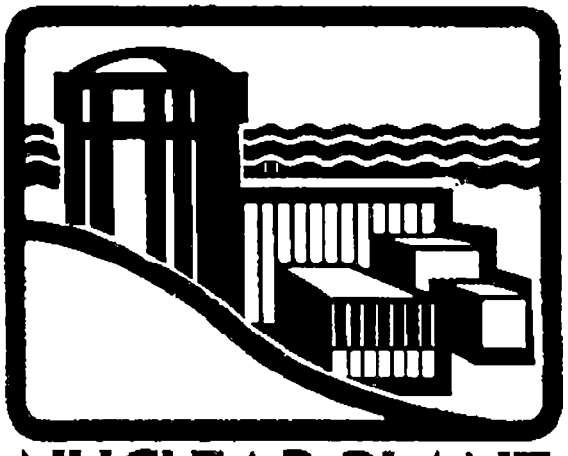
PALISADES



NUCLEAR PLANT

CPCo MEETING WITH NRC
PALISADES PRESSURIZER SAFE-END CRACK ENGINEERING ANALYSIS AND ROOT CAUSE EVALUATION

OCTOBER 12, 1993

Consumers Power

POWERING MICHIGAN'S PROGRESS

CONSUMERS POWER COMPANY MEETING WITH NRC

PALISADES PRESSURIZER SAFE-END CRACK

ENGINEERING ANALYSIS AND ROOT CAUSE EVALUATION

OCTOBER 12, 1993

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PALISADES PRESSURIZER SAFE-END CRACK

Sequence of Events

June, 1993	Possible flaw identified in pressurizer relief valve nozzle safe end. Flaw evaluated and dispositioned as original construction flaw which would not grow.
September 16	Shortly after plant reached hot shutdown (532°F, 2060 psia), 0.2 gpm leak was identified on containment sump level instrumentation. Auxiliary operator reported steam leak in pressurizer shed shortly thereafter.
September 17	Plant achieved cold shutdown permitting direct visual and NDE examination of crack. Crack was characterized as circumferential, in safe end of pipe, near safe-end to pipe weld and approximately three inches in length.

PALISADES PRESSURIZER SAFE-END CRACK

Safety Assessment

- The root cause of the PWSCC crack in the pressurizer relief valve safe-end has been identified.

- The repaired safe-end will be suitable for service for at least one more operating cycle. A final repair to the pressurizer relief valve safe-end and PORV line will be performed during the next refueling outage as committed in the long term action plan.

- Similar (circumferential) through wall cracks in other similar pressurizer or PCS nozzle safe-ends or welds containing inconel or austenitic stainless steel are unlikely based on our understanding of the pressurizer nozzle safe-end cracking mechanism and the inspections of potentially susceptible nozzle safe-ends that have been performed.

- However, should a crack occur in a nozzle safe-end, the leak will be detected by the Palisades leakage monitoring systems and the plant safely shut down before the load carrying capability of the safe-end will no longer be adequate to withstand normal and faulted condition.

- The Palisades primary coolant system leakage monitoring systems are capable of detecting leakage from the type and size of crack that occurred in the pressurizer relief valve nozzle safe-end within a very short period of time and prompt action will be taken on the part of the operations personnel to shut down the plant.

PALISADES PRESSURIZER SAFE-END CRACK

Metallurgical Examination Results

- Cracking mode was intergranular in the safe-end heat affected zone.
- Cracking initiated from the inside surface of the safe-end.
- Cracks ran perpendicular to the inside surface without significant propagation in the axial and azimuthal directions.
- The outside surface of the crack consisted of six discontinuous cracks, the total length was about three inches.
- An original weld root repair, apparently made from the inside of the safe-end, was located adjacent to the crack initiation point.
- There was evidence of grinding on the root of the weld.
- A significant (1/16") mismatch existed between the ID of the safe-end and the stainless steel pipe.
- Shallow intergranular penetrations were present on the inner surface of the heat affected zone.
- A black oxide was present on the fracture surface indicating that the crack had existed for some period of time prior to the refueling outage.
- Base metal and heat affected zone consist of large, course grains with a continuous intergranular carbide network and numerous fine intrragranular carbides.
- Chemical composition of base metal and heat affected zone is consistent with ASME purchase specification for this material.
- The failure has been attributed to primary water stress corrosion cracking (PWSCC).

PALISADES PRESSURIZER SAFE-END CRACK

Cause of the Safe-End Crack

- For primary water stress corrosion cracking (PWSCC), there are three required factors. These are:

  A metallurgical condition
  An aggressive steam/water environment
  A threshold stress valve

- The safe-end was made of a material with a high yield stress which made it vulnerable to PWSCC. These vulnerabilities are reflected by:

  A high hardness HRC-22
  A high yield stress of 77KSI
  An assumed low (1600-1700°F) post-forging heat treatment

- The safe-end was exposed to stagnant steam at approximately 640°F. The material would be highly sensitive to cracking at this temperatures.

- Although externally applied piping system loads induced by pressure, weight, thermal expansion and potential flow stratification meet design requirements and are relatively low, significant local stresses appear to exist at the Inconel/stainless steel safe-end weld. These stresses are due to

  The field welding process
  The mismatch in pipe/safe-end sizes
  The materials mismatched thermal effects

- To add insight into the load assessment, analysis of dissimilar metal effects and flow stratification were conducted. These evaluations led to the conclusion that the external piping loads as induced by the piping support system were not the driving forces for the crack. The local pipe/safe-end configuration and fabrication process are viewed as the primary contributors.

PALISADES PRESSURIZER SAFE-END CRACK

Repair of the Pressurizer Safe-End

- The heat affected zone of the inconel material was removed and the weld prep machined to assure that the new heat affected zone does not have intergranular penetration or discontinuities that could act as stress risers.
- The fit-up between the safe-end and stainless steel pipe was improved.
- The inner surface of the weld was ground smooth.
- There were no repair weld deposits made to the inner surface of the weld.
- All of these improvements and changes will extend potential crack initiation time significantly, resulting in increased lifetime for the repaired weld as compared to the original weld.
- Very conservative crack propagation calculations indicate more than 20 months at temperature and pressure (640°F, 2060 psia) would be required for a crack to grow through wall.
- Time to crack initiation in the heat affected zone of the new safe-end should be comparable to that of the original safe-end heat affected zone. No credit is taken for this in the calculation of time to through wall cracking.
- Therefore, the lifetime of the new weld will exceed one operating cycle.

PALISADES PRESSURIZER SAFE-END CRACK

Examination Methods and Flaw Detectability

- **Examination Methods:**
  - Dye penetrant (PT), Radiography (RT) and Ultrasonic Testing (UT) were used to examine the PORV line and the additional sample of welds.
  - Where possible, a combination of examinations was used to provide the highest confidence possible.
  - Also where possible, mockups were utilized to further address the effectiveness of the examinations performed.
  - All examinations were preformed utilizing qualified personnel and procedures.
  - For all new welds, radiography and dye penetrant were utilized for acceptance.
- **Flaw Detectability:**
  - CPCo has a high degree of confidence in the NDE performed and our ability to detect the crack sizes which could grow through wall during the next plant operating cycle.
  - CPCo believes radiography did detect the crack in the PORV safe-end in June of 199

PALISADES PRESSURIZER SAFE-END CRACK

Evaluation of Other Pressurizer Nozzles

- **Other pressurizer nozzles:** pressurizer heater sleeves (120), temperature instruments (2), level instruments (8), safety relief valve flanges (3), spray nozzle, surge nozzle

- **Pressurizer heater sleeves:**

  Palisades heater sleeves characterized as having low susceptibility by CE Owners Group Work. Characterization was based on low yield strength of Inconel material and absense of pre-installation reaming of the sleeves.

  Cracking mode will be axially oriented and thus do not represent a safety issue.

  Visual inspections per CEOG recommendations have not identified any leaks.

- **Temperature instruments:**

  Similar to heater sleeves in that nozzles are solid inconel and welded to pressurizer by partial penetration welds.

  Cracks will axially oriented and thus not a safety concern.

- **Level instruments:**

  Low alloy nozzles with inconel transition piece and stainless steel safe-end.

  Consumers Power sponsored study of residual stresses in the butt welds in these nozzles. The study showed only compressive or relatively low tensile stresses.

  Inconel material is of relatively low yield strength (46.2 ksi).

  Conclusion is that cracking is unlikely but would be axially oriented.

PALISADES PRESSURIZER SAFE-END CRACK

Evaluation of Other Pressurizer Nozzles

- **Safety Relief Valve Flanges:**

  Fabricated from same high yield strength inconel as relief valve nozzle.

  Axial stresses may be present in the flanges.

  Flanges experiences high temperatures in the pressurizer vapor space.

  Nozzles and flanges were stress relieved in the shop during fabrication of the pressurizer. This will reduce weld residual stresses.

  Nozzle to flange weld area has been extensively inspected with dye penetrant, ultrasonic and radiography with no recordable indications noted. Also, there is no evidence in original construction records or from visual examination of the welds of any weld repairs made from the inside of the nozzle.

  Conclusion is that flanges are suitable for service.

- **Spray Nozzle:**

  Fabricated from same high yield strength inconel as relief valve nozzle.

  Axial stresses may be present in the welds and safe-end.

  Temperature of the welds and safe-end is considerably lower than the pressurizer steam due to the continuous flow of cooler water at cold leg temperature.

  The nozzle and nozzle-to-safe-end weld were stress relieved in the shop during fabrication of the pressurizer. This will reduce weld residual stresses. The safe-end-to-pipe weld was not stress relieved.

  Nozzle-to-safe-end and safe-end-to-pipe welds were examined using dye penetrant and radiography with no recordable indications.

  Conclusion is that spray nozzle and safe-end are suitable for service.

PALISADES PRESSURIZER SAFE-END CRACK

Evaluation of Other Pressurizer Nozzles

- **Surge Nozzle:**

  Fabricated from a different heat of inconel material with significantly lower yield strength (51 ksi). The time to initiation of PWSCC will be approximately four times as long for this material as the pressurizer relief valve safe-end material, everything else being the same.

  Axial stresses may be present in the welds and safe-end.

  Temperature of the welds and safe-end is near the pressurizer temperature.

  The nozzle and safe-end are exposed to pressurized water as opposed to steam. The majority of PWSCC occurrences, and all leaks, in industry pressurizers involving inconel material of the same ASME material specification (SB-166) have occurred in the pressurizer steam space.

  The nozzle and nozzle-to-safe-end weld were stress relieved in the shop during fabrication of the pressurizer. This will reduce weld residual stresses. The safe-end-to-pipe weld was not stress relieved.

  Nozzle-to-safe-end and safe-end-to-pipe welds were examined using IGSCC qualified ultrasonic techniques last weekend with no recordable indications.

  Conclusion is that surge nozzle and safe-end are suitable for service.

PALISADES PRESSURIZER SAFE-END CRACK

Cracking of Other Materials in PCS Dissimilar Metal Welds

- Intergranular stress corrosion cracking (IGSCC) has occurred in the heat affected zone of austenitic stainless steel welds in boiling water reactors.
- The root cause of these failures has been attributed to high weld residual stresses, sensitization of the stainless steel and high oxygen content in the coolant.
- The solution for the BWR problem has been the introduction of a hydrogen water chemistry designed to lower the electro-chemical potential of the coolant. In operating PWRs, the normal ECP is well below the critical potential for IGSCC.
- There have been several events of IGSCC in PWRs, including CRDM seal housings, but all have involved geometries where aerated water was trapped.
- Therefore, IGSCC in the austenitic stainless steel welds in the Palisades PCS is unlikely.

PALISADES PRESSURIZER SAFE-END CRACK

Inconel 600 Program

PALISADES PRESSURIZER SAFE-END CRACK

Long Term Corrective Actions

- The design of the pressurizer relief valve nozzle and PORV line will be reviewed and appropriate modifications will be made during the next refueling shutdown to assure a suitable lifetime for the pressurizer relief valve nozzle safe-end. The review will be coordinated with the safety-related piping reverification project (SRPRP) review of the PORV line.

- A comprehensive program to deal with Inconel 600 issues at Palisades will be developed. The program will guide future inspections and replacements of Inconel 600 components in the primary coolant system.

- Further evaluation and qualification of non-destructive examination techniques for detection of PWSCC will be conducted. This will include development of an appropriate mockup and qualification of ultrasonic examination techniques for PWSCC.